Performance of Glass as Concrete Aggregates

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ABSTRACT

A condition survey was carried out on three buildings where glass had been used as concrete aggregate in pre-cast cladding panels. At the time of the survey the buildings had been in service for over ten years. Degradation had occurred and was in the form of cracking, spalling and bowing of panels and is believed to be due to alkali-aggregate reaction. A deleterious expansion due to the reactivity was demonstrated by conducting tests on specimens obtained from selected panels. The type, grading and amount of glass along with the exposure conditions appeared to be the main factors controlling the expansion of the concrete.

INTRODUCTION

A condition survey was carried out on three buildings in the Metropolitan Toronto area in the 1970's. These buildings were built with specially made pre-cast concrete cladding panels made with white cement and broken glass aggregates. In most cases the glass aggregates had been used as an exposed decorative facing material cast against a normal aggregate concrete backing. Some of these panels exhibited either progressive deterioration or changes in their physical shape.

Since some glass is known to cause deleterious reactions (1) with alkalis in cement, this paper mainly focuses on this particular aspect of its performance. A brief reference is included to freeze-thaw exposure, simply to emphasize the point that any distress in a concrete is often a combination of several factors and it is difficult to isolate one from another.

OUTDOOR EXPOSURE CONDITIONS

Observations on three selected buildings are reported here. The buildings varied in height from one storied (#1) to multi-level high rise towers (#2 and #3). All three were built in the 1960's and at the time of the condition survey the buildings had already gone through about 10 to 15 years of service. Based on the criteria established by Sturrup et al (2), the number of freeze-thaw cycles the structures had gone through during that period is between 450 and 720. A high level of moisture content is required in a concrete to cause distress due to freeze-thaw action. Continuous supply of moisture is also required to cause deleterious reactivity due to alkali-aggregate reaction in a concrete. Since the panels in question were vertically oriented any rain or melting snow water would drain away relatively quickly. In the cladding panels the movement of water may have been slower than normal due to the many channels at the surface, created by the exposed nature of the glass aggregates. It is therefore possible that this slow movement provided ample time for the cement paste to absorb moisture in its micropores.

FIELD OBSERVATIONS

Building #1 was a church with cladding panels of size approximately 3 x 4 metres. The facing material of the panels was about 25 to 30 mm thick. The coarse aggregates were mainly composed of crushed quartz stone and broken white-milky glass. The fine aggregates appeared to be a good quality silica sand. The cement was a white portland cement. No visible distress such as cracking, spalling or bowing was noticed on the panels. The building was in excellent condition.

Building #2 was a high rise tower where cladding panels had been used to the full height of the building and the ground level columns. All these panels were made with broken glass as coarse aggregate and the fine aggregate was silica sand. The cement was white portland cement. A few localized hairline cracks were noticed in some of the panels at the street level. Evidence of bowing and closing of joints was visible from a distance. This is illustrated in Figure 1.

Building #3 was a high rise tower where all sides of the building were clad with panels, as a window framing. A close inspection of this building revealed a significant number of cracks of various magnitudes in many of the panels. Spalling of concrete at localized sections was also noticed. A typical condition is shown in Figure 2. The facing concrete was composed of coarse and fine aggregates, both from broken glass, and white cement. A few sections of the concrete were obtained for further laboratory examination and testing.

LABORATORY EXAMINATION

Six sections were brought to the laboratory and prepared for testing. Many fine cracks, and soft and friable cement paste around the coarse glass particles were observed. Evidence of white reaction products was noticed under a stereoscopic microscope.

Set A - Prisms (Figure 3) of approximately 40x40x285 mm were saw cut, two from each of the sections marked 3, 4 and 5 and four from each of sections 2 and 6. The section 1 was severely cracked and no attempt was made to cut prisms from this specimen. Length change measuring gauge points were fixed at the ends of these prisms. These are termed as prism sets A1 and A2.

Set B - Lumps of broken pieces of the specimens were subjected to a high temperature in excess of 800° C in a kiln and the glass was partially separated from the dehydrated cement paste. The glass particles were further cleaned in hydrochloric acid and repeatedly washed with water till no trace of acid was detected. Two prisms (Figure 3) of size 25x25x285 mm were then made with the mix proportions as used in the job, using white cement and the glass recovered from the specimens as described above. These were termed as set (B) prisms. The mix proportions were as follows:

Cement	=	360 kg/m^3
Coarse aggregate (size 5 mm to 12 mm)	=	356 kg/m^3
Fine aggregate (<5 mm)	=	1424 kg/m^3
Water to cement ratio	=	0.45

Set C - In addition to the above, four more 25x25x285 mm prisms were made using the above materials and the mix proportions recommended in ASTM-C227. These are termed as set (C) prisms.

Tests

All these three sets of prisms were cured in sealed containers maintained at 95 to 100% relative humidity and at 38° C. Periodic length change measurements were made on each prism at four week intervals up to 61 weeks. The average change in length of all sets are recorded in Tables 1 and 2.

The set (a) prisms were expected to absorb significant moisture and result in expansion during its initial curing condition. In order to obtain the net expansion due to any reactivity, the expansion due to the moisture movement was subtracted from the length measurements.

Results

The change in length is shown in Figure 4. It is noted that the average expansion due to moisture movement was about 0.04% and occurred within a week. The net expansions are shown in Figure 5. The expansion results of other prisms are included in Figure 5.

The air void systems of the concrete was determined according to ASTM-C457 test procedure. The air content was a 2.1% with a specific surface of 15.7 mm^{-1} and a spacing factor of 0.28 mm. The sample was non-air-entrained concrete.

The oxide analyses of the glass and the white cement used in set (B) and set (C) prisms were as follows:

1. for Glass: (Specific gravity = 2.32)

	%
Silica as SiO_2	60.12
Sodium as Na_2O	8.45
Potassium as K_2O	0.48

2. for White Cement: Total alkalinity as Na_2O 0.51%

DISCUSSIONS

The limited tests reported here indicate that providing enough moisture is available the expansion of concrete made with some glass aggregates will continue for a prolonged period. This expansion is accompanied by the formation of microcracks which are filled with reaction products. It is interesting to note that the deleterious expansion is caused even with a low alkali cement. This confirms the findings reported by Mielenz (1) on opal glass and soft glass samples.

The building #3 under investigation was subsequently repaired by epoxy injection of major cracks to restore the structural integrity of the panels. The surface was then coated with a breathing type of sealant. This prevented further ingress of moisture. After more than ten years in service, this procedure appeared to have shown satisfactory results.

CONCLUDING REMARKS

The field examination of these buildings indicated that glass if used as concrete aggregates may or may not cause distress in the structure. The performance possibly depends on the type, amount and grading of the glass, the composition of the cement and the environment to which the concrete is exposed.

Laboratory tests under accelerated curing conditions will usually confirm potential expansivity of glass aggregates.

It appears that eliminating moisture ingress reduces the progress of this type of reactivity under field conditions.

ACKNOWLEDGEMENTS

The data reported was provided by Trow Ltd.

REFERENCES

1. Meilenz, R.C. 1954. Petrographic Examination of Concrete Aggregates. Proc. of ASTM, Vol. 54.

2. Sturrup, V.R., Clendenning, T.G. 1969. The Evaluation of Concrete by Outdoor Exposure. Highway Research Record, HRR268, Portland Cement Concrete.

TABLE 1

PER CENT LENGTH CHANGE OF PRISMS (40X40X285 mm) SAW CUT FROM THE PANEL OF BUILDING #3 AND CURED AT 38°C, 95-100% RH. (SET A1 AND A2)

Set No.	Prism* No.	Age - Weeks								Remarks
		2	4	8	12	16	20	28	61**	
A1	2a	0.052	0.068	0.097	0.135	0.163	0.147	0.205	0.278	These prisms were measured with a 200 mm demec gauge length measuring device. The values are average of readings on 3 sets of gauges mounted on three long sides of the prism.
	2b	0.049	0.062	0.078	0.089	0.118	0.130	0.156	0.223	
	2c	0.038	0.037	0.052	0.060	0.062	0.072	0.082	0.089	
	2d	0.046	0.061	0.080	0.097	0.126	0.155	0.247	0.228	
	6d	0.036	0.054	0.080	0.117	0.162	0.193	0.202	0.275	
	Min	0.036	0.037	0.052	0.060	0.063	0.072	0.082	0.089	
	Max	0.052	0.068	0.097	0.135	0.163	0.193	0.247	0.278	
	Avg	0.044	0.056	0.077	0.100	0.126	0.139	0.178	0.219	
A2	3a	0.054	0.064	0.082	0.073	0.100	0.109	0.130	-	These prisms were measured with a length change comparator, the gauge pins were fixed with epoxy at each end of the prism by drilling holes.
	3b	0.056	0.081	0.122	0.086	0.139	0.157	0.177	-	
	4b	0.044	0.067	0.100	0.085	0.117	0.129	0.172	-	
	5a	0.055	0.086	0.104	0.094	0.112	0.120	0.139	-	
	5b	0.058	0.080	0.137	0.094	0.159	0.181	0.201	-	
	6a	0.059	0.076	0.134	0.094	0.147	0.158	0.183	-	
	6c	0.054	0.074	0.108	0.074	0.129	0.149	0.165	-	
	Min	0.044	0.064	0.082	0.073	0.100	0.109	0.130	-	
	Max	0.059	0.086	0.137	0.094	0.159	0.181	0.201	-	
	Avg	0.054	0.075	0.112	0.086	0.129	0.143	0.167	-	

Note: The average values are plotted in Figure 5 after subtracting a constant factor 0.04% from each reading. This factor is due to initial moisture movement.

* Prisms marked 4a and 6b were used to determine moisture movement characteristics of the concrete (refer to Figure 4).

** The prisms were cured at 23°C, 95-100% RH between 28 and 61 weeks.

TABLE 2

PER CENT LENGTH CHANGE OF PRISMS (25X25X285 mm) MADE IN THE LABORATORY USING GLASS AGGREGATES RECOVERED FROM THE BROKEN PIECES OF THE PANEL OF BUILDING #3, CURED AT 38°C, 95-100% RH. WHITE CEMENT (EQUIVALENT Na_2O=0.51%) WAS USED.
(SET B AND C)

Set No.	Prism No.	Age - Weeks								Remarks
		2	4	8	12	16	20	28	61*	
B	10a	0.002	0.008	0.023	0.023	0.053	0.117	0.266	0.904	glass aggregate grading same as field concrete
	10b	0.000	0.006	0.010	0.026	0.090	0.223	**	-	
	Avg	0.001	0.007	0.017	0.025	0.072	0.170	0.266	0.904	
C	11a	-0.017	-0.007	0.006	0.012	0.026	0.058	0.073	0.901	glass aggregate grading according to ASTM-C227
	11b	-0.008	-0.003	0.009	0.014	0.033	0.071	0.179	0.813	
	12a	-0.012	-0.007	0.007	0.008	0.023	0.023	0.035	0.662	
	12b	-0.011	-0.004	0.010	0.014	0.026	0.037	0.069	0.702	
	Min	-0.008	-0.003	0.006	0.008	0.023	0.023	0.035	0.662	
	Max	-0.017	-0.007	0.010	0.014	0.033	0.071	0.179	0.901	
	Avg	-0.012	-0.005	0.008	0.012	0.027	0.047	0.089	0.770	

* The prisms were cured at 23°C, 95 to 100% RH between 28 and 61 weeks.
** Prisms cracked unsuitable for further measurements.

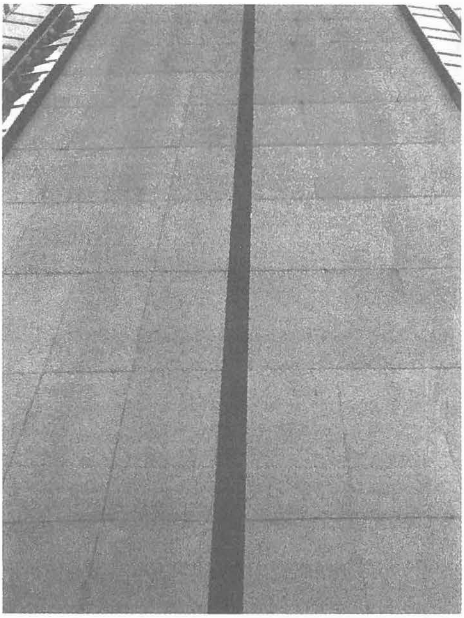
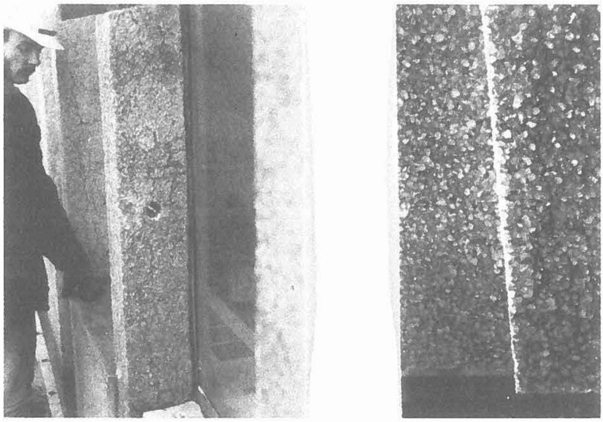
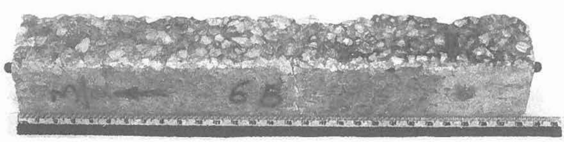


Figure 1: Precast concrete cladding of Building #2. Note the tightening of joints between pannels, causing localized distress.



(A) (B)

Figure 2: Cracks seen on the precast cladding panels of Building #3. A small core was obtained from the panel shown in (A) for laboratory examination.



(A) Prism Cut From the Pre-Cast Panel (40 x 40 x 285 mm)

(B) Prism Made in the Laboratory with Glass Aggregates Recovered from the Panel (25 x 25 x 285 mm)

Figure 3: A view of the concrete prism saw-cut from a panel of Building #3 and that of a prism made in the laboratory with glass aggregates recovered from the panel.

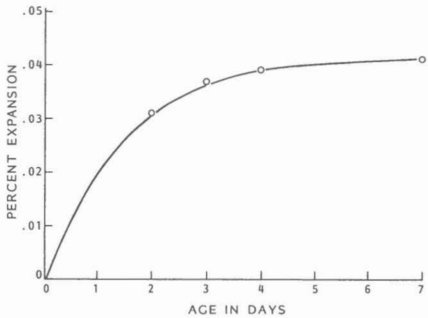


FIGURE 4

PERCENT LENGTH CHANGE OF SAW CUT PRISMS (40 x 40 x 285mm) DUE TO SWELLING ON IMMERSION IN WATER AT 23°C AFTER INITIAL DRYING AT 75°C FOR 3 DAYS AND THEN COOLING AT 23°C

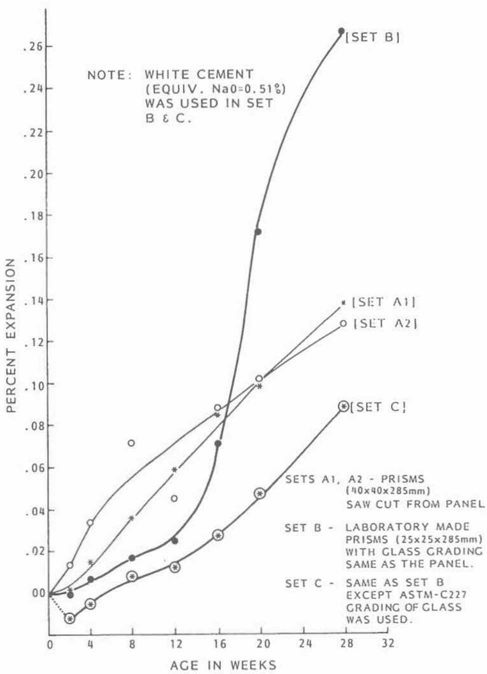


FIGURE 5

PERCENT LENGTH CHANGE OF PRISMS CURED AT 38°C AND 95 TO 100% RH [THE EXPANSION VALUES OF SETS A1 & A2 (TABLE 1) ARE PLOTTED AFTER SUBTRACTING A FACTOR OF 0.041% DUE TO INITIAL MOISTURE MOVEMENT OF THE CONCRETE

See Figure 4.